ECR Ion Sources for H^- ion production : prospects and first results

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Introduction: H- for HPA

SNS , ESS, neutrino factory will need high currents of protons

These future machines will need long pulses of negative ions, with a reliability not yet reached at such currents.

The emittance of the source should be as low as possible, in order to match the beam to the pre-accelerator (less than 0.2 pi mm-mrad rms normalized).

Moreover the pulses should be perfectly reproducible and noiseless.

An advance is therefore necessary in order to increase both the levels of currents delivered by the negative ion sources, and their reliability.

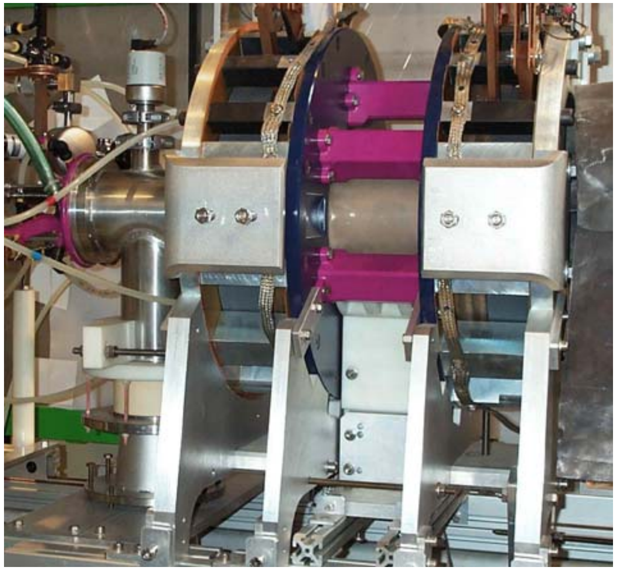
⇒ *Research effort in Europe:* 9 laboratories join their efforts to improve negative Ion sources; different technologies will be tested and developped

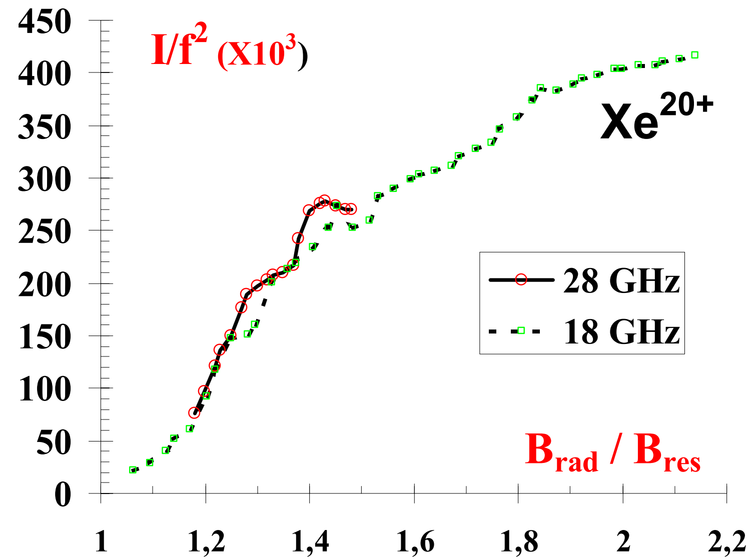
ECR Ion sources: state of the art

ECRIS for heavy ions: *mirror confined plasmas*

- production of a high density (> 10^{12} cm-3) plasma at high frequency
- production of a very energetic electron population ($E_{mean} = 20 – 40$ keV)
- performances are strongly dependent on the frequency ($n_e \sim \omega^2$)

=> Very efficient production of Multiply Charged Ions



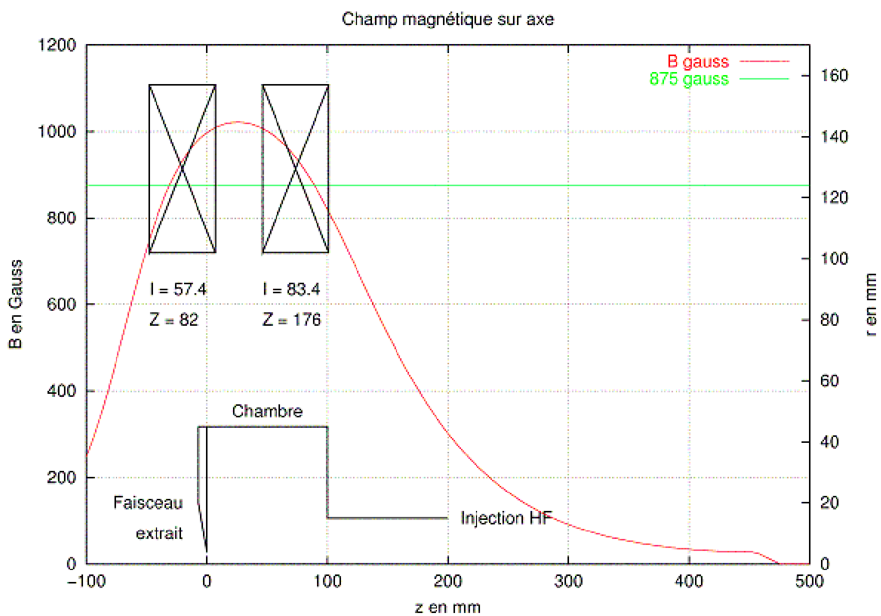


ECR Ion sources: state of the art (continued)

<u>ECRIS for intense beams of light ions: </u>*low confinement plasmas*

(pioneer work at Chalk River and Los Alamos)

- 2,45 GHz operation
- $n_e > 5\ 10^{11}\ cm^{-3}$
- $T_e \sim 10 – 20$ eV
- Phf ~ 850 watts
- Volume ~ 0.6 liter
- J ~ 250 mA / cm2 H+



The SILHI source at Saclay

Interest of an ECR-produced plasma for a NIS

It is possible to produce a dense plasma with an ECRIS

ECRIS can be run in dc or pulsed mode, without any problem

ECRIS do not need any cathodes, nor filaments => high reliability

However, today, there is no ECRIS able to produce H- currents as requested by HPA (ESS, neutrino factory…).

⇒ Research has started (in the frame of a European RTD programme HPRI-2001-50011), to develop and optimize an ECRNIS (at CEA)

Existing negative ion sources: short survey

1. **Surface Plasma Sources** (Penning type) :

=> Large power (tens of kW) in a small volume, but with a poor confinement of the plasma

⇒ Cs injection

⇒ Efficient production of H-

However an ECRIS cannot be run in SPS regime: a minimum volume is required for HF launching and absorption

⇒ An ECR source cannot be compared to that kind of source, with such a high power density for plasma production.

Existing negative ion sources: short survey (continued)

2.Volume sources

Multicusps with filaments (Berkeley,Frankfurt…) :

Volume of the source: < 1 liter
Arc power: 50 kW
Current density of extracted H- (with Cs) : 150 mA/cm2

=> Required power density : 50 kW / l

Multicusps with plasma production through RF excitation (Berkeley, Oak Ridge…):

Same volume as above…
For SSC: 35-50 kW , 25 mA H-
For SNS: 50 kW, 50 mA H-

Existing negative ion sources: short survey (continued)

Volume sources RF discharges with axial magnetic field

Production of a high current of H-, without any Cs : 80 mA H- at DESY
More than 15 kW injected into a volume of typically 1 liter

SUMMARY:

These volume sources have a confinement of the plasma (either cusp, or axial field);
They need a high power and power density;
The H- production, and ratio (H-/e-) are improved by Cs injection

Is ECR plasma production compatible with NI ?

<u>Dense plasma production with ECR</u> requires a minimum volume => volume source

It is not necessary to produce such hot electrons as in ECRIS for heavy ions => <u>no mirror confinement</u> will be used

Low confinement ECR plasmas also produce <u>energetic electrons</u>, which can efficiently produce excited hydrogen molecules:

$$H_2 + e^- \rightarrow H_2^*$$

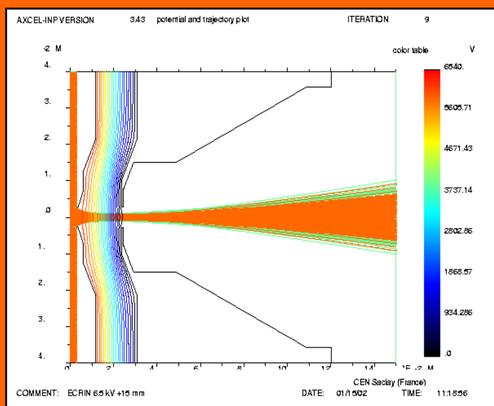
These hot electrons must however be kept away from the extraction zone: this problem is complex since efficient plasma production through ECR is related to the magnetic profile.

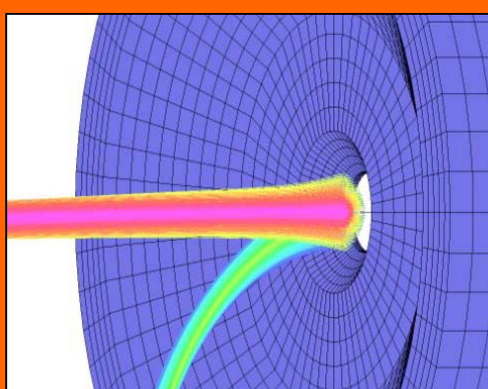
An ECR ion source for H- was developed at Argonne in 1995 (Spence et al):
=> succesfull H- production by changing the magnetic field in the extraction zone.

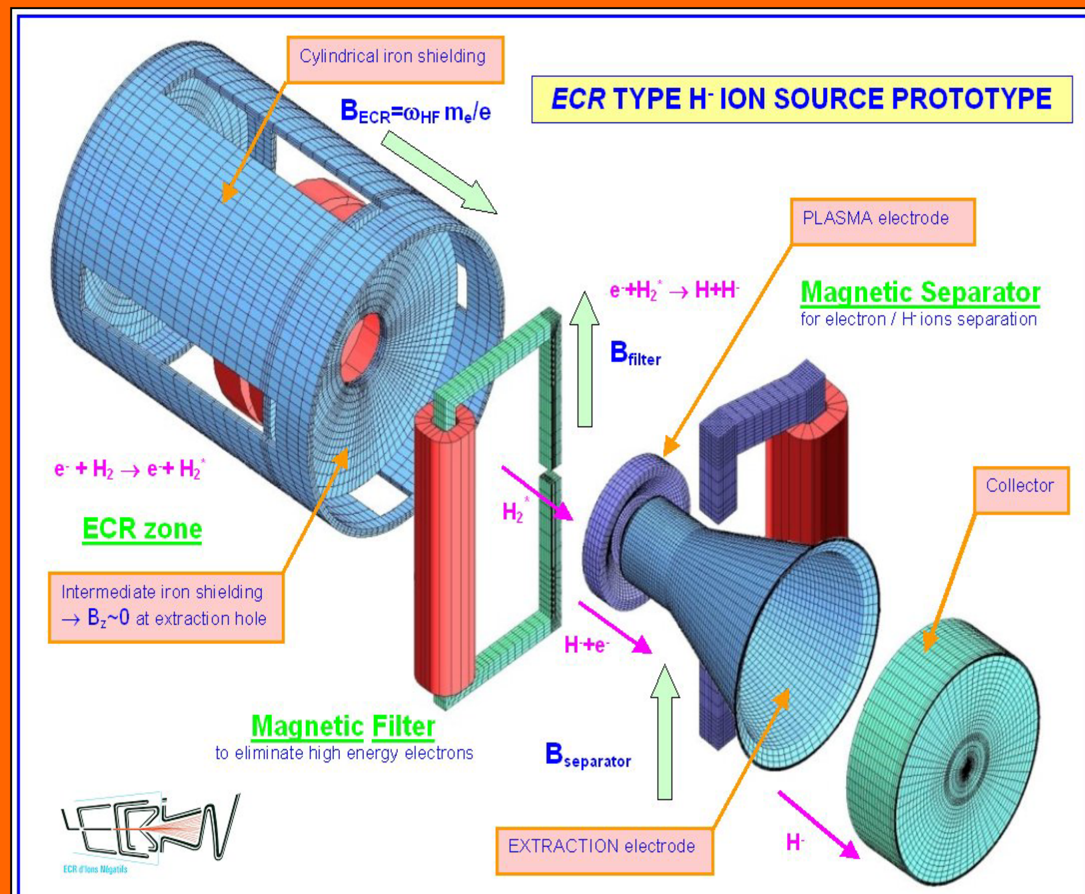
We followed the same idea to modify the SILHI source for NI production

First negative ions obtained at CEA- Saclay (1/3)

Magnetic calulations and trajectories of particles

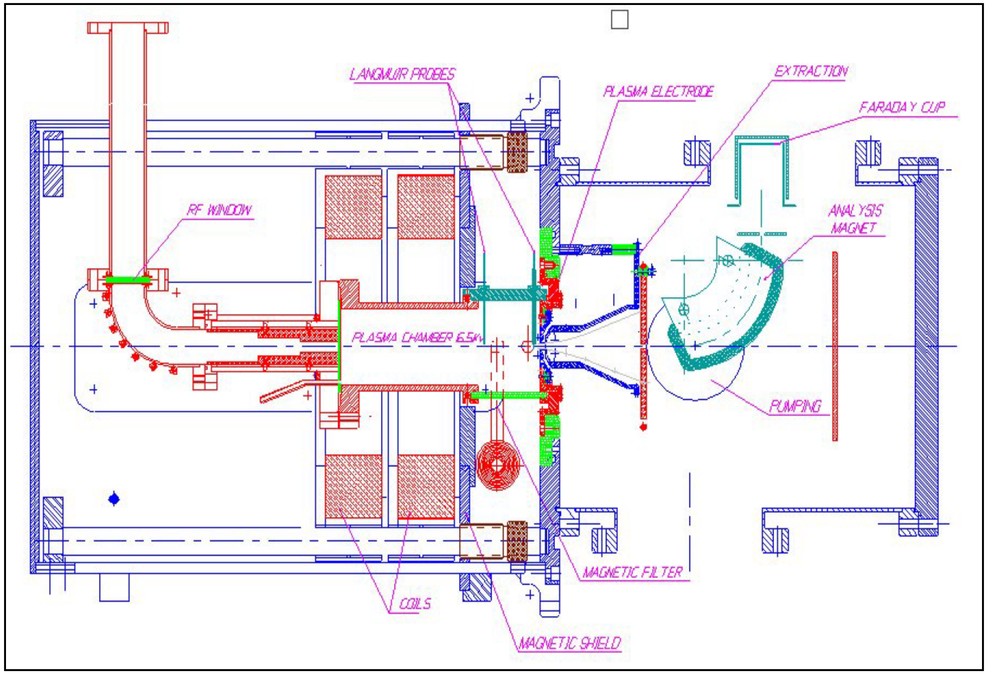






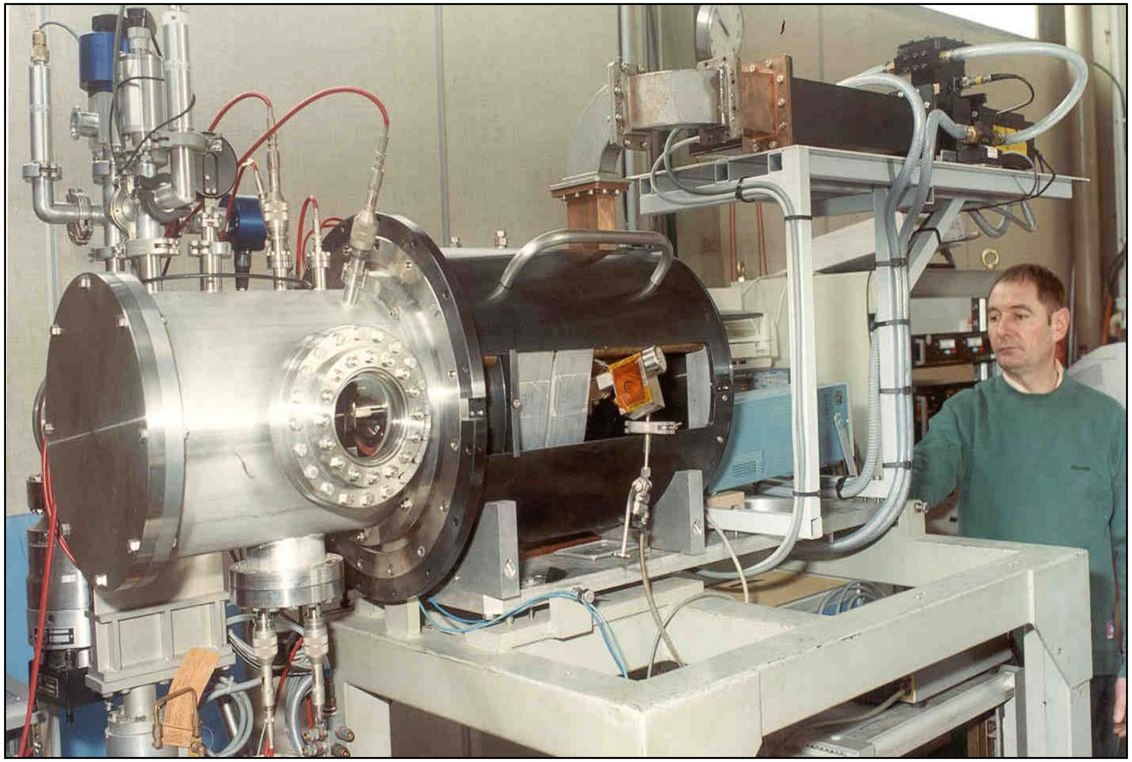
First negative ions obtained at CEA- Saclay (2/3)

The modified SILHI source:



The extraction zone has been modified
A magnetic filter + analyzing magnet have been installed

First negative ions obtained at CEA- Saclay (3/3)



A few tens of mA (total) have been extracted; the first H- ions have been identified but complementary experiments are required.
We are at the starting point of optimisation.

Other possible conceptual designs; prospects (1/3)

A multicusp confinement field could be tested: however this type of ECRIS has already been developed, and the results obtained then should be analyzed:

• at TRIUMF such a plasma was produced:

2 mA H- produced , 600 watts injected

• at Ube (Japan) some work has been performed related to a fusion program

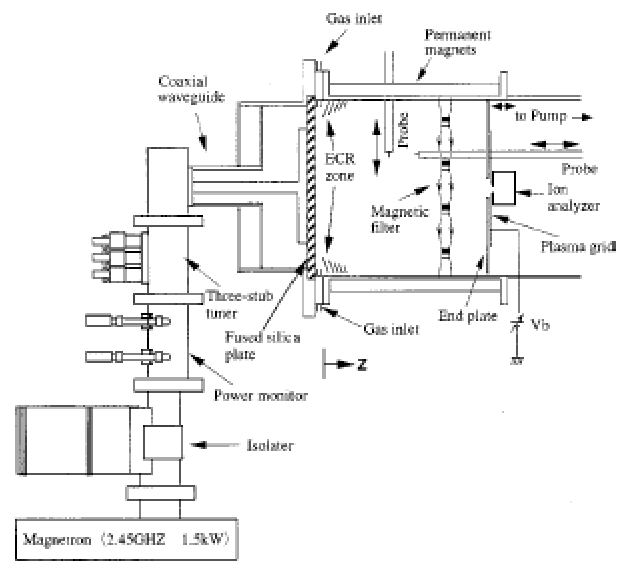


FIG. 1. Schematic diagram of the ECR negative ion source with the line-cusp resonance magnet.

Other possible conceptual designs; prospects (2/3)

Power required to sustain the plasma:

From the experiments performed at Argonne we may imagine that, in order to produce 50 mA of H-, around **20 kW** at 2,45 GHz could be necessary (this has to be verified first).

Another possibility could be to work at a higher frequency:

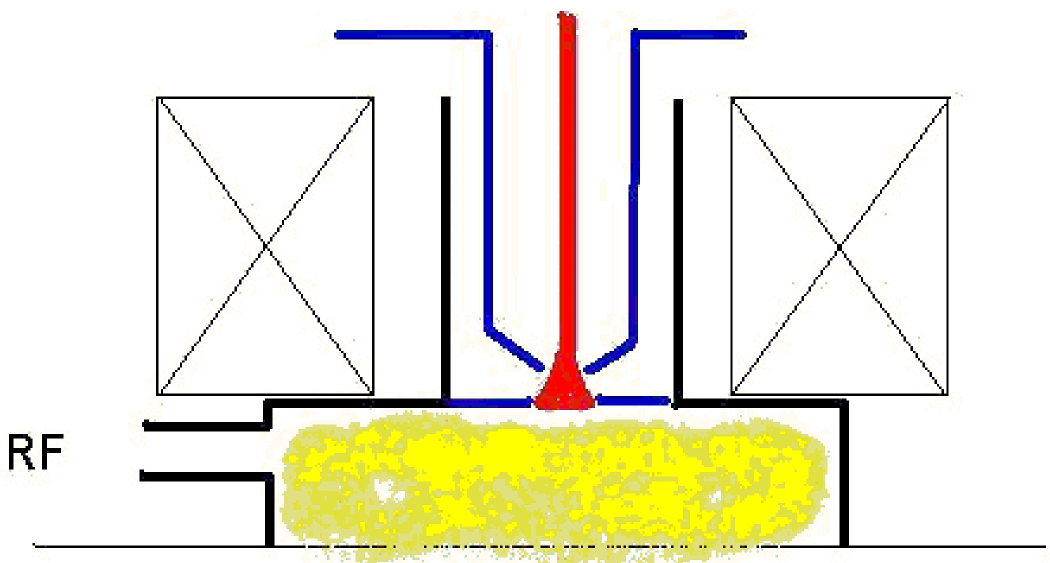
• **frequency scaling** is likely to occur also in low confinement ECR plasmas
$\Rightarrow$ Improvement in performances by working at 10 GHz

•**A larger ratio power/volume** can be achieved at a higher frequency:
The volume of an ECR source is necessarily related to the wavelength (in SILHI we have a kind a monomode cavity) : the volume may be smaller at 10 GHz

A SILHI-type homothetic magnetic configuration at 10 GHz will be tested

Other possible conceptual designs; prospects (3/3)

Still more innovative configurations can be proposed: «radial » extraction of H- ions ?



However:

role of the magnetic field on the beam emittance ?

Is the « magnetic filter » too strong ?

Conclusion, further work

ECR plasma for NIS is a new technology, which needs important development:

• 2002-2003 : optimization of SILHI type NIS; research for innovative concepts

• 2003 and later : tests of SILHI type at HV; development of LEBT

• end 2003 10 GHz source design completed

• end 2004 10 GHz tests completed at 10 kV

• if these tests are promissing, this 10 GHz NIS will be installed on a HV platform